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(54) ECHO CANCELLATION METHOD AND DEVICE

(57) An echo cancelation method is disclosed. The method includes: dividing a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal; performing, by using an AEC module, adaptive filtering echo cancelation processing on the to-be-processed low-band audio signal, and skipping performing adaptive filtering echo cancelation processing on the to-be-processed high-band audio signal, to generate a preliminary echo cancelation signal; performing, by using an RES module, envelope prediction echo suppression on a high-band signal in a preliminary echo cancelation frequency domain signal, and calculating and outputting a residual echo suppression coefficient; performing, by using the RES module, echo suppression on a low-band signal in a preliminary echo cancelation frequency domain signal, and outputting a processing result; and multiplying the output result and the residual echo suppression coefficient, and outputting a signal of which echoes are canceled. In addition, an echo cancelation device is provided. In the embodiments of the present invention, high-band processing and low-band processing are separately performed on a to-be-processed signal, thereby not only effectively reducing a calculation amount of echo cancelation, but also solving a problem of echo leakage existing on sub-band edges in the prior art.

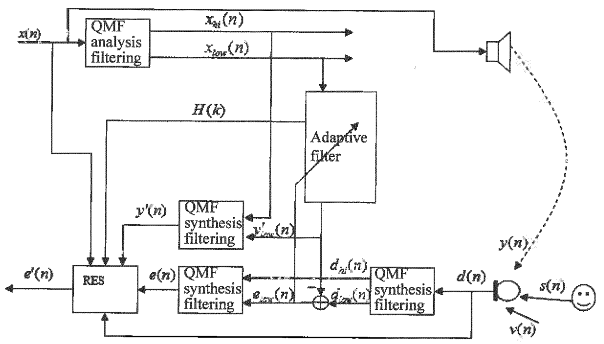

FIG. 4

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Description

[0001] This application claims priority to Chinese Patent Application No. 201210387313.8, filed with the Chinese Patent Office on October 12, 2012 and entitled "ECHO CANCELATION METHOD AND DEVICE", which is incorporated herein by reference in its entirety.

TECHNICAL FIELD

[0002] The present invention relates to the audio signal processing field, and in particular, to an echo cancelation method and device.

BACKGROUND

[0003] FIG. 1 is a schematic diagram of an application scenario of an echo cancelation technology. A far-end signal transmitted from a network passes through a CODEC, that is, the far-end signal is decoded by a CODEC module for analogy-to-digital conversion, and then is sent to a loudspeaker for playing. A microphone collects a near-end signal, and at the same time collects the far-end signal (namely, an echo) played by the loudspeaker. After echo cancelation processing is performed on signals collected by the microphone, echoes in the signals collected by the microphone are canceled, and only the near-end signal is left. The near-end signal is coded by the CODEC module and then is sent to a far end via the network. If the echoes in the signals collected by the microphone are not canceled, after the signals are sent to the far end, the far end hears a sound of its own. A purpose of the echo cancelation technology is to cancel echoes as much as possible, and reserve the near-end signal.

[0004] Echo cancelation processing generally includes two parts: AEC (Adaptive Echo Canceller) adaptive echo cancelation and RES (Residual Echo Suppressor) residual echo suppression. In the adaptive echo cancelation, an adaptive filter is used to simulate a spatial echo path, and cancel the echoes in the signals collected by the microphone. Generally, due to impact of factors such as noise, an AEC module cannot completely cancel the echoes, and therefore an RES module needs to further perform echo suppression processing on a residual echo. Adaptive filtering has such algorithms as: NLMS, RLS and MDF (Multidelay block frequency domain adaptive filter) algorithm, where the MDF algorithm is an implementation form of the NLMS algorithm in a frequency domain. When a reverberation time is relatively long and a sampling rate is relatively high, an adaptive filter needs a very long order. For example, when the reverberation time is 300 ms and the sampling rate is 48 khz, a required order is 48000x0.3=14400; as a result, a calculation amount of the adaptive filter is great, thereby increasing a device cost. The present invention provides an echo cancelation algorithm of low complexity.

[0005] In the prior art, to reduce complexity, adaptive sub-band filtering is used to solve the problem.

[0006] As shown in FIG. 2, sub-band division is performed separately for a near-end signal $d(n)$ and a far-end signal x(n), and a bandwidth of each sub-band is 250 Hz; therefore, for 8 KHz, there are 16 sub-bands in total; for 16 KHz, there are 32 sub-bands in total; for 32 KHz, there are 64 sub-bands in total. Echo cancelation is performed for each sub-band by using the NLMS algorithm, and integration is performed for the sub-bands to obtain a residual echo signal.

[0007] However, in the prior art, at least the following problem exists:

> Echo leakage exists on sub-band edges. It is found by debugging that an echo attenuation amount of a sub-band adaptive filter is obviously insufficient on the sub-band edges, and a strong single-frequency signal (which sounds like a bang, and relatively affects a subjective feeling) is usually left.

SUMMARY

[0008] In view of this, it is necessary to provide an echo cancelation method and device, so as to solve the foregoing problem.

[0009] An embodiment of the present invention provides an echo cancelation method, and the method includes:

> dividing a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal;
> performing, by using an AEC module, adaptive filtering echo cancelation processing on the to-be-processed low-band audio signal; and
> performing, by using an RES module, envelope prediction echo suppression on the to-be-processed high-band audio signal, performing echo suppression on the

[0010] to-be-processed low-band audio signal, and outputting a signal after processing. By using the method, not only a calculation amount in echo cancelation is effectively reduced, but also a problem of echo leakage existing on sub-band edges is solved.

[0011] In addition, an embodiment of the present invention provides an AEC module for echo cancelation, including:

a reference signal analysis filter, configured to process a reference signal into a high-band reference signal and a low-band reference signal, output the high-band reference signal to an artificial echo synthesis filter, and output the low-band reference signal to an adaptive filter;
a to-be-processed audio signal analysis filter, configured to process a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal, output the to-be-processed high-band audio signal to a preliminary echo cancelation signal synthesis filter, and output the to-be-processed low-band audio signal to the adaptive filter;
the adaptive filter, connected to the reference signal analysis filter and the to-be-processed audio signal analysis filter, and configured to perform adaptive filtering processing on the low-band reference signal to generate a low-band artificial echo signal, and output the low-band artificial echo signal to the artificial echo synthesis filter; perform adaptive filtering processing on the to-be-processed low-band audio signal to generate a low-band preliminary echo cancelation signal, and output the low-band preliminary echo cancelation signal to the preliminary echo cancelation signal synthesis filter;
the artificial echo synthesis filter, connected to the adaptive filter and configured to synthesize the high-band reference signal and the low-band artificial echo signal into an artificial echo signal, and output the artificial echo signal to an RES device; and
the preliminary echo cancelation signal synthesis filter, connected to the adaptive filter and configured to synthesize the to-be-processed high-band audio signal and the low-band preliminary echo cancelation signal into a preliminary echo cancelation signal, and output the preliminary echo cancelation signal to an RES module.

[0012] In addition, an embodiment of the present invention further provides an RES module for echo cancelation, including:

an FFT transformation module, configured to perform FFT transformation on a reference signal, a to-be-processed audio signal, an artificial echo signal, and a preliminary echo cancelation signal, to generate a reference frequency domain signal, a to-be-processed frequency domain audio signal, an artificial echo frequency domain signal, and a preliminary echo cancelation frequency domain signal, respectively; and input the to-be-processed frequency domain audio signal, the artificial echo frequency domain signal, and the preliminary echo cancelation frequency domain signal to an RES low-band module, and input the reference frequency domain signal and the preliminary echo cancelation frequency domain signal to an RES high-band module;
the RES high-band module, configured to perform envelope prediction echo suppression on a high-band signal in the preliminary echo cancelation frequency domain signal, and calculate and output a residual echo suppression coefficient; and
the RES low-band module, configured to perform echo suppression on a low-band signal in the preliminary echo cancelation frequency domain signal, and output a processing result.

[0013] The device not only effectively reduces a calculation amount in echo cancelation, but also solves a problem of echo leakage existing on sub-band edges.

BRIEF DESCRIPTION OF DRAWINGS

[0014] To describe the technical solutions in the embodiments of the present invention or in the prior art more clearly, the following briefly introduces the accompanying drawings required for describing the embodiments or the prior art. Apparently, the accompanying drawings in the following description show merely some embodiments of the present invention, and persons of ordinary skill in the art may still derive other drawings from these accompanying drawings without creative efforts.

FIG. 1 is a flowchart of a method in the background of the present invention;
FIG. 2 is a flowchart of a method in the prior art in the background of the present invention;
FIG. 3 is a structural diagram of a device according to Embodiment 1 of the present invention;
FIG. 4 is a flowchart of a method according to Embodiment 1 of the present invention;
FIG. 5 is a flowchart of a method according to Embodiment 1 of the present invention;
FIG 6 is a flowchart of a method according to Embodiment 1 of the present invention;
FIG. 7 is a reference diagram of a sub-band division manner according to Embodiment 1 of the present invention;

FIG. 8 is an exemplary diagram of an echo impulse response and an energy decay curve according to Embodiment 1 of the present invention; and

FIG. 9 is a flowchart of QMF analysis and processing by a synthesis filter according to Embodiment 1 of the present invention.

DESCRIPTION OF EMBODIMENTS

[0015] To make the objectives, technical solutions, and advantages of the embodiments of the present invention clearer, the following clearly and completely describes the technical solutions in the embodiments of the present invention with reference to the accompanying drawings in the embodiments of the present invention. Apparently, the described embodiments are some but not all of the embodiments of the present invention. All other embodiments obtained by persons of ordinary skill in the art based on the embodiments of the present invention without creative efforts shall fall within the protection scope of the present invention.

[0016] An embodiment of the present invention provides an echo cancelation method, so as to cancel an echo in a to-be-processed audio signal and output a signal of which echoes are canceled.

[0017] Referring to FIG. 3, a reference signal $x(n)$ (namely, a far-end signal, where the reference signal and the far-end signal have a same meaning in this disclosure) is output to a loudspeaker for playing; a microphone collects a to-be-processed audio signal $d(n)$, where the to-be-processed audio signal includes an echo signal $y(n)$, a local-end signal s(n) and a noise v(n); the to-be-processed audio signal is processed by using an AEC module and an RES module to cancel the echo signal $y(n)$ and the noise v(n) and to reserve the local-end signal. Specifically, referring to FIG. 4, the method includes the following steps:

S1: An AEC module performs preliminary echo cancelation processing on a to-be-processed audio signal, and generates a preliminary echo cancelation signal $e(n)$.

[0018] The AEC module processes a reference signal x(n) and the to-be-processed audio signal d(n), outputs the preliminary echo cancelation signal $e(n)$, an artificial echo signal $y'(n)$, and a low-band echo filtering coefficient $H(k)$ of a frequency domain; and outputs the reference signal x(n) and the to-be-processed audio signal $d(n)$ to an RES module. Specifically, the step includes:

1. Generate an artificial echo signal $y'(n)$ according to a reference signal $x(n)$.

[0019] After the reference signal $x(n)$ is processed by a QMF analysis filter, a high-band reference signal $x_{hi}(n)$ and a low-band reference signal $x_{low}(n)$ are generated; the high-band reference signal $x_{hi}(n)$ is output to a QMF synthesis filter and the low-band reference signal $x_{low}(n)$ is output to an adaptive filter.

[0020] After the low-band reference signal $x_{low}(n)$ is processed by the adaptive filter, a low-band artificial echo signal $y'_{low}(n)$ is generated, and is output to the QMF synthesis filter.

[0021] After the high-band reference signal $x_{hi}(n)$ and the low-band artificial echo signal $y'_{low}(n)$ are processed by the QMF synthesis filter, the artificial echo signal $y'(n)$ is generated, and is output to an RES module.

2. Generate the preliminary echo cancelation signal $e(n)$ according to the to-be-processed audio signal $d(n)$.

[0022] After the to-be-processed audio signal $d(n)$ is processed by the QMF synthesis filter, a to-be-processed high-band audio signal $d_{hi}(n)$ and a to-be-processed low-band audio signal $d_{low}(n)$ are generated; the to-be-processed high-band audio signal $d_{hi}(n)$ is output to the QMF synthesis filter.

[0023] The low-band artificial echo signal $y'_{low}(n)$ subtracted from the to-be-processed low-band audio signal $d_{low}(n)$, to obtain a low-band preliminary echo cancelation signal $e_{low}(n)$, and the low-band preliminary echo cancelation signal $e_{low}(n)$ is output to the QMF synthesis filter module.

[0024] After the to-be-processed high-band audio signal $d_{hi}(n)$ and the low-band preliminary echo cancelation signal $e_{low}(n)$ are processed by the QMF synthesis filter, the preliminary echo cancelation signal $e(n)$ is generated, and is output to the RES module.

3. Obtain the low-band echo filtering coefficient $H(k)$ of the frequency domain by calculation by the adaptive filter in a process of processing the low-band reference signal.

[0025] In addition, the AEC module further outputs the reference signal $x(n)$ and the to-be-processed audio signal $d(n)$ to the RES module, where the reference signal x(n) and the to-be-processed audio signal $d(n)$ are used as ancillary signals for the RES module to perform further echo cancelation processing.

[0026] S2: An RES module further performs echo cancelation processing on the preliminary echo cancelation signal $e(n)$, and generates a signal of which echoes are canceled, referring to FIG. 5.

[0027] S201: The RES module performs fast Fourier transformation (FFT, Fast Fourier Transformation) separately on the reference signal $x(n)$, the to-be-processed audio signal $d(n)$, the artificial echo signal $y'(n)$, and the preliminary echo cancelation signal $e(n)$, to generate a corresponding reference frequency domain signal $X(k)$, a to-be-processed frequency domain audio signal $D(k)$, an artificial echo frequency domain signal $Y'(k)$, and a preliminary echo cancelation frequency domain signal $E(k)$, respectively; inputs the to-be-processed frequency domain audio signal $D(k)$, the artificial echo frequency domain signal $Y'(k)$, and a residual frequency domain echo signal $E(k)$ to an RES low-band module, and inputs the reference frequency domain signal $X(k)$, the low-band echo filtering coefficient $H(k)$, and the preliminary echo cancelation frequency domain signal $E(k)$ to an RES high-band module.

[0028] S203: The RES high-band module performs envelope prediction echo suppression on a high-band signal in the preliminary echo cancelation frequency domain signal $E(k)$ (a high-band signal for short), and calculates and outputs a residual echo suppression coefficient $G_{he}(k)$; the RES low-band module performs echo suppression by using an existing echo suppression technology on a low-band signal in the preliminary echo cancelation frequency domain signal $E(k)$ (a low-band signal for short), and outputs a processing result, referring to FIG. 6.

[0029] It should be noted that, to eliminate an aliasing effect, the high-band signal and the low-band signal overlap. If there are 512 spectral lines, the RES low-band module performs residual echo suppression on spectral lines 1 to 263, and the RES high-band module performs suppression on spectral lines 231 to 512; therefore, 32 spectral lines overlap in total.

1. A process of calculating the residual echo suppression coefficient by the RES high-band module is as follows: calculating a gain of each sub-band according to energy $E(i)$ of each sub-band of the preliminary echo cancelation frequency domain signal $E(k)$, energy $U(i)$ of each sub-band of the reference frequency domain signal $X(k)$, energy $\tilde{E}(i)$ of each sub-band of a residual echo frequency domain signal, a high-band envelope prediction coefficient $g_l(i)$, and an attenuation factor factor of the high-band envelope prediction coefficient; and calculating a gain $G_{he}(k)$ of each spectral line of the high band, namely, a residual echo coefficient, according to the gain of each sub-band. Specifically, the process includes:

(1) Calculate the energy $E(i)$ of each sub-band of the preliminary echo cancelation frequency domain signal $E(k)$, the energy $U(i)$ of each sub-band of the reference frequency domain signal $X(k)$, the energy $\tilde{E}(i)$ of each sub-band of the residual echo frequency domain signal, the high-band envelope prediction coefficient $g_l(i)$, and the attenuation factor factor of the high-band envelope prediction coefficient.

A. The RES high-band module estimates an echo of the high band by using an envelope prediction method, and then performs suppression. The so-called envelope prediction is a manner of estimating, without considering an effect of a phase, energy of an echo of a current frame by using energy of a reference signal of several previous frames in the frequency domain, which is shown in the following formula:

$$\widetilde{E}(i) = \sum_{l=0}^{L-1} g_l(i) U_{-l}(i) \qquad (1)$$

In the formula, i represents a serial number of a divided sub-band in the frequency domain, and L is a quantity of frames used for the envelope prediction; $g_l(i)$ represents the first coefficient of the i^{th} sub-band, and $U_{-l}(i)$ represents energy of the i^{th} sub-band of the first frame in the reference frequency domain signal $X(k)$. When a quantity of spectral lines is 512, for a sub-band division manner of the high-band RES, reference is made to FIG. 7, where there are 5 sub-bands in total, and the sub-bands overlap in a triangular window manner.

It should be noted that, in this embodiment, the sub-bands overlap in the triangular window manner, to which it is not limited, and the sub-bands may also overlap in a sine window or rectangle window manner.

$\tilde{E}(i)$ represents energy, estimated for the i^{th} sub-band, of a residual echo frequency domain signal. As described above, the to-be-processed audio signal $d(n)$ includes three parts: the echo signal $y(n)$, the local-end signal $s(n)$, and the noise $v(n)$. After the AEC module performs preliminary echo cancelation processing on the to-be-processed audio signal $d(n)$, the preliminary echo cancelation signal $e(n)$ is generated. After FFT transformation is performed on the signal, the preliminary echo cancelation frequency domain signal $E(k)$ is generated. Therefore, the preliminary echo cancelation frequency domain signal $E(k)$ also includes three parts: the residual echo frequency domain signal, a local-end frequency domain signal, and a noise frequency domain signal.

B. A formula for calculating $U(i)$ is as follows:

$$U(i) = \sum_{k=kl(i)}^{kh(i)} w_k(i)\left|X(k)\right|^2 \quad (2)$$

In the formula, $kl(i)$ represents a start frequency of the i^{th} sub-band, $kh(i)$ represents an end frequency of the i^{th} sub-band, and $w_k(i)$ represents a weight coefficient of each frequency. If $kc(i)$ is a central frequency of the i^{th} sub-band, a value of $w_k(i)$ is calculated by using the following formula:

$$\begin{cases} w_k(i) = \dfrac{(k-kl(i))}{(kc(i)-kl(i))} & \mathrm{k} >= kl(i)\ \&\&\mathrm{k} <= kc(i) \\ w_k(i) = 1 - \dfrac{(k-kc(i))}{(kh(i)-kc(i))} & \mathrm{k} > kc(i)\ \&\&\mathrm{k} <= kh(i) \end{cases} \quad (3)$$

where, a value of $kl(i)$ is $kc(i-1)$, and a value of $kh(i)$ is $kc(i+1)$; by using these values, a smooth effect of a sound can be enhanced.

In the foregoing manner of calculating $U(i)$, energy of each sub-band of the preliminary echo cancelation frequency domain signal $E(k)$ may be calculated:

$$E(i) = \sum_{k=kl(i)}^{kh(i)} w_k(i)\left|E(k)\right|^2 \quad (4)$$

C. If an echo impulse response $h_n(i)$ of each sub-band is known, the envelope prediction coefficient $g_l(i)$ may be calculated as follows:

$$g_l(i) = \sum_{n=l*N}^{l*N+N-1} h_n(i) * h_n(i) \quad (5)$$

In the formula, N represents a frame length. Because only the low-band echo filtering coefficient $H(k)$ can be obtained, a high-band filtering coefficient can only be approximated by using the low-band echo filtering coefficient. A specific implementation method is: performing IFFT transformation on $H(k)$ to obtain a low-band impulse response of a time domain, and then performing high-pass filtering to obtain a high sub-band impulse response $h0_n$; then, calculating the envelope prediction coefficient by using the foregoing formula:

$$g_l(i)=\sum_{n=l*N}^{l*N+N-1} h0_n * h0_n \quad (6)$$

It may be seen from the foregoing formula that each sub-band of the high band uses a same envelope prediction coefficient.

D. An attenuation factor factor of the envelope prediction coefficient is calculated. FIG. 8 is an example of an echo impulse response and an energy decay curve (EDC). It may be seen that the EDC is basically linear in a middle part. The EDC is defined as:

$$EDC(i)=10*\log 10\left(\sum_{n=i}^{L*N} h_n * h_n\right) \quad (7)$$

where i represents a time point; if an impulse response is divided into L frames, the EDC of each frame is calculated as follows:

$$\begin{aligned} EDC(l) &= 10*\log 10\left(\sum_{n=l*N}^{L*N} h_n * h_n\right) \\ &= 10*\log 10\left(\sum_{m=l}^{L} g_m\right) \end{aligned} \quad (8)$$

for a frame EDC, an EDC slope means an EDC difference between adjacent frames, that is:

$$q = EDC(l) - EDC(l-1) \quad (9)$$

where q is the EDC slope. Therefore,

$$\begin{aligned} q &= 10*\log 10\left(\sum_{m=l}^{L} g_m\right) - 10*\log 10\left(\sum_{m=l-1}^{L} g_m\right) \\ &= 10*\log 10\left(\frac{\sum_{m=l}^{L} g_m}{\sum_{m=l-1}^{L} g_m}\right) \\ &\approx 10*\log 10\left(\frac{\sum_{m=l}^{\infty} g_m}{\sum_{m=l-1}^{\infty} g_m}\right) \end{aligned} \quad (10)$$

The attenuation factor of the envelope prediction coefficient between the adjacent frames is:

$$factor = g_m / g_{m-1} \quad (11)$$

then,

$$\begin{aligned} q &= 10 * \log 10(factor) \\ factor &= 10^{q/10} \end{aligned} \quad (12)$$

In this way, the attenuation factor of the envelope prediction coefficient can be calculated by calculating the slope q of the EDC. The slope of the EDC may be calculated by using a linear recurrence method. It may be seen that, except initial tens of milliseconds belonging to an early-stage echo, the EDC is linear, that is, the attenuation factor of the envelope prediction coefficient is a fixed value. A relatively large quantity of frames are used when an echo is estimated by using the envelope prediction coefficient. For example, if an echo tail lasts for 256 ms and a length of each frame is 8 ms, 32 frames are required; as a result, a larger storage space and calculation amount are required, while by using a feature that the attenuation factor is a fixed value, the storage space and calculation amount may be reduced. A specific method is as follows:

$$\begin{aligned} \tilde{E}(i) &= \sum_{l=0}^{l0} g_l(i) U_{-l}(i) + \sum_{l=l0+1}^{L-1} g_l(i) U_{-l}(i) \\ &= \sum_{l=0}^{l0} g_l(i) U_{-l}(i) + \tilde{E}_{r,m}(i) \end{aligned} \quad (13)$$

In the formula, a value of ^{l0} is 7, that is, the first 8 frames (64 ms) are considered as the early-stage echo, and echoes following the first 8 frames are considered as a later-stage echo. The later-stage echo is represented by $\tilde{E}_{r,m}(i)$, where m represents a current frame and r represents the later-stage echo. By using a formula $factor = g_l / g_{l-1}$, an approximate estimation manner of $\tilde{E}_{r,m}(i)$ may be obtained:

$$
\begin{aligned}
\widetilde{E}_{r,m}(i) &= \sum_{l=l0+1}^{L-1} g_l(i)U_{-l}(i) \\
&\approx \sum_{l=l0+1}^{\infty} g_l(i)U_{-l}(i) \\
&= \sum_{l=l0+2}^{\infty} g_l(i)U_{-l}(i) + g_{l0+1}(i)U_{-l0-1}(i) \\
&= factor * \sum_{l=l0+2}^{\infty} g_{l-1}(i)U_{-l}(i) + g_{l0+1}(i)U_{-l0-1}(i) \\
&= factor * \sum_{l=l0+1}^{\infty} g_l(i)U_{-l-1}(i) + g_{l0+1}(i)U_{-l0-1}(i) \\
&= \widetilde{E}_{r,m-1}(i) * factor + g_{l0+1}(i)U_{-l0-1}(i)
\end{aligned} \tag{14}
$$

(2) Calculate a gain of each sub-band. The gain of each sub-band is calculated by using the following formulas:

$$\widetilde{E}_{db}(i) = 10 * \log 10\left(\widetilde{E}(i)\right) \tag{15}$$

where $\widetilde{E}_{db}(i)$ is a decibel value of $\widetilde{E}(i)$;

$$E_{db}(i) = 10 * \log 10\left(E(i)\right) \tag{16}$$

$E_{db}(i)$ where $E_{db}(i)$ is a decibel value of E(i); and

$$
\begin{cases}
G(i) = 0.1\,, & E_{db}(i) - \widetilde{E}_{db}(i) <= 0 \\
G(i) = \left(E_{db}(i) - \widetilde{E}_{db}(i)\right) * (1 - 0.1)/10 + 0.1\,, & \\
 & (E_{db}(i) - \widetilde{E}_{db}(i) > 0) \,\&\, (E_{db}(i) - \widetilde{E}_{db}(i) < 10) \\
G(i) = 1, & E_{db}(i) - \widetilde{E}_{db}(i) >= 10
\end{cases} \tag{16}
$$

In the foregoing formula, G(i) represents the gain of each sub-band; $E_{db}(i)$ - $\widetilde{E}_{db}(i)$ <= 0 represents that an estimated echo is louder than an original echo; in this case, a lower limit 0.1 is used as the gain of the sub-band; $E_{db}(i)$ - $\widetilde{E}_{db}(i)$ >= 10 represents that the original echo is 10 DB louder than the estimated echo, where, in this case, it may be basically considered that no echo exists in signals collected by a microphone, and an upper limit 1 is used as the gain of the sub-band; ($E_{db}(i)$ - $\tilde{E}_{db}(i)$ > 0) & ($E_{db}(i)$ - $\tilde{E}_{db}(i)$ < 10) represents that the original echo is 0 DB to 10 DB louder than the estimated echo, where, in this case, a value of the gain of the sub-band ranges from 0.1 to 1, and is in direct proportion to a DB difference of ($E_{db}(i)$ - $\tilde{E}_{db}(i)$).

(3) After calculating the gain of the sub-band, obtain a gain $G_{he}(k)$ of each spectral line of a high band, that is, a residual echo suppression coefficient can be obtained by using gain interpolation between adjacent sub-bands.

$$G(k) = w_k(i)G(i) + w_k(i-1)G(i-1) \quad (17)$$

where $W_k(i)$ is a coefficient used in the calculation of the energy of each sub-band in the foregoing.

S205: Multiply a result output by the RES low-band module and the residual echo suppression coefficient output by the RES high-band module, to obtain and output a signal $E'(k)$ of which echoes are canceled.

S207: Perform inverse fast Fourier transformation (IFFT, Inverse Fast Fourier Transformation) on the signal $E'(k)$ of which the echoes are canceled, then backfill a noise, and output a final processed signal.

It should be noted that a noise backfill module determines, according to an NLP identifier, whether a current frame is a residual echo; if yes, backfills a noise; otherwise, determines a VAD identifier; if the current frame is the noise, stores a noise signal in a noise buffer area.

In the embodiment of the present invention, a signal is divided into a high-band signal and a low-band signal, an existing echo cancelation algorithm is used for the low-band signal, and an envelope prediction echo suppression algorithm is used for the high-band signal, thereby achieving an effect of greatly reducing calculation complexity, and at the same time avoiding a problem of echo leakage on sub-band adaptive filtering edges.

[0030] In addition, an embodiment of the present invention provides an AEC module for echo cancelation, including:

a reference signal analysis filter, configured to process a reference signal into a high-band reference signal and a low-band reference signal, output the high-band reference signal to an artificial echo synthesis filter, and output the low-band reference signal to an adaptive filter;

a to-be-processed audio signal analysis filter, configured to process a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal, output the to-be-processed high-band audio signal to a preliminary echo cancelation signal synthesis filter, and output the to-be-processed low-band audio signal to the adaptive filter;

the adaptive filter, connected to the reference signal analysis filter and the to-be-processed audio signal analysis filter, and configured to perform adaptive filtering processing on the low-band reference signal to generate a low-band artificial echo signal, and output the low-band artificial echo signal to the artificial echo synthesis filter; and perform adaptive filtering processing on the to-be-processed low-band audio signal to generate a low-band preliminary echo cancelation signal, and output the low-band preliminary echo cancelation signal to the preliminary echo cancelation signal synthesis filter;

the artificial echo synthesis filter, connected to the adaptive filter and configured to synthesize the high-band reference signal and the low-band artificial echo signal into an artificial echo signal, and output the artificial echo signal to an RES device; and

the preliminary echo cancelation signal synthesis filter, connected to the adaptive filter and configured to synthesize the to-be-processed high-band audio signal and the low-band preliminary echo cancelation signal into a preliminary echo cancelation signal, and output the preliminary echo cancelation signal to an RES module.

[0031] It should be noted that a process of QMF analysis and processing by a synthesis filter is shown in FIG. 9. After an input signal x(n) is filtered by a low-pass filter H0(z) and a high-pass filter H1(z), two-fold downsampling is performed, and then low-band processing and high-band processing are performed separately; then, two-fold upsampling is performed separately, and synthesis filters F0(z) and F1(z) perform filtering; a synthesized signal y(n) is output after adding up. To eliminate aliasing, the filters are subject to the following limitation:

$$H1(z)=H0(-z)$$

$$G0(z)=2*H1(-z)=2*H0(z)$$

$$G1(z)=-2*H1(-z)=-2*H0(z)$$

[0032] In a time domain, h0(i)=h(i), i=0,1 ... N-1, where N is a length of the filter; then:

$$h1(i)=(-1)^i h(i)$$

$$g0(i)=2h(i)$$

$$g1(i)=-2*(-1)^i h(i)$$

[0033] Therefore, during design of the filter, only the low-pass analysis filter needs to be designed, and other filters may be obtained according to the low-pass analysis filter with reference to the foregoing parameters.

[0034] In addition, an embodiment of the present invention further provides an RES module for echo cancelation, including:

an FFT transformation module, configured to perform FFT transformation on a reference signal, a to-be-processed audio signal, an artificial echo signal, and a preliminary echo cancelation signal, to generate a reference frequency domain signal, a to-be-processed frequency domain audio signal, an artificial echo frequency domain signal, and a preliminary echo cancelation frequency domain signal, respectively; and input the to-be-processed frequency domain audio signal,
the artificial echo frequency domain signal, and the preliminary echo cancelation frequency domain signal to an RES low-band module, and input the reference frequency domain signal and the preliminary echo cancelation frequency domain signal to an RES high-band module;
the RES high-band module, configured to perform envelope prediction echo suppression on a high-band signal in the preliminary echo cancelation frequency domain signal, and calculate and output a residual echo suppression coefficient; and
the RES low-band module, configured to perform echo suppression on a low-band signal in the preliminary echo cancelation frequency domain signal, and output a processing result.

[0035] The RES high-band module includes:

a module for calculating energy of each sub-band of a preliminary echo cancelation frequency domain signal, configured to calculate energy of each sub-band of the preliminary echo cancelation frequency domain signal and output the energy of each sub-band of the preliminary echo cancelation frequency domain signal to a sub-band gain calculation module;
a module for calculating energy of each sub-band of a reference frequency domain signal, configured to calculate energy of each sub-band of the reference frequency domain signal and output the energy of each sub-band of the reference frequency domain signal to the sub-band gain calculation module;
an IFFT transformation module, configured to perform IFFT transformation on a low-band echo filtering coefficient to generate a low-band impulse response of a time domain, and output the impulse response to a high-pass filtering module;
the high-pass filtering module, connected to the IFFT transformation module and configured to perform high-pass filtering processing on the low-band impulse response of the time domain to generate a high-band impulse response, and output the high-band impulse response to a high-band envelope prediction coefficient calculation module;
the high-band envelope prediction coefficient calculation module, connected to the high-pass filtering module and configured to calculate a high-band envelope prediction coefficient according to the high-band impulse response, and output the high-band envelope prediction coefficient to an EDC slope calculation module and the sub-band gain calculation module;
the EDC slope calculation module, connected to the high-band envelope prediction coefficient calculation module and configured to calculate an EDC slope and output the EDC slope to an attenuation factor calculation module;
the attenuation factor calculation module, connected to the EDC slope calculation module, and configured to calculate an attenuation factor according to the EDC slope, and output the attenuation factor to the sub-band gain calculation

module;
the sub-band gain calculation module, connected to the module for calculating energy of each sub-band of a preliminary echo cancelation frequency domain signal, the module for calculating energy of each sub-band of a reference frequency domain signal, the high-band envelope prediction coefficient calculation module, and the attenuation factor calculation module, and configured to calculate a gain of a sub-band according to the energy of each sub-band of the preliminary echo cancelation frequency domain signal, the energy of each sub-band of the reference frequency domain signal, the high-band envelope prediction coefficient, and the attenuation factor, and output the gain of the sub-band to a module for calculating a gain of each spectral line of a high band; and
the module for calculating a gain of each spectral line of a high band, connected to the sub-band gain calculation module and configured to calculate a gain of each spectral line of a high band, namely, a residual echo suppression coefficient, according to the gain of the sub-band.

[0036] The device provided in the embodiments of the present invention divides a signal into a high-band signal and a low-band signal, uses an existing echo cancelation algorithm for the low-band signal, and uses an envelope prediction echo suppression algorithm for the high-band signal, thereby achieving an effect of greatly reducing calculation complexity, and at the same time, avoiding a problem of echo leakage on sub-band adaptive filtering edges. Finally, it should be noted that the foregoing embodiments are merely intended for describing the technical solutions of the present invention but not for limiting the present invention. Although the present invention is described in detail with reference to the foregoing embodiments, persons of ordinary skill in the art should understand that they may still make modifications to the technical solutions described in the foregoing embodiments or make equivalent replacements to some technical features thereof, without departing from the spirit and scope of the technical solutions of the embodiments of the present invention.

Claims

1. An echo cancelation method, wherein the method comprises the following steps:

dividing a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal;
performing adaptive filtering echo cancelation processing on the to-be-processed low-band audio signal, and skipping performing adaptive filtering echo cancelation processing on the to-be-processed high-band audio signal, to generate a preliminary echo cancelation signal; and
performing envelope prediction echo suppression on a high-band signal in a preliminary echo cancelation frequency domain signal, and calculating and outputting a residual echo suppression coefficient; performing, by using an RES module, echo suppression on a low-band signal in the preliminary echo cancelation frequency domain signal, and outputting a processing result; and multiplying the output result and the residual echo suppression coefficient, and outputting a signal of which echoes are canceled.

2. The echo cancelation method according to claim 1, wherein the dividing a to-be-processed audio signal is performed by using QMF analysis filtering.

3. The echo cancelation method according to claim 1, wherein the step B comprises:

generating a low-band preliminary echo cancelation signal after the to-be-processed low-band audio signal undergoes the adaptive filtering processing; and
generating the preliminary echo cancelation signal after the low-band preliminary echo cancelation signal and the to-be-processed high-band audio signal undergo synthesis filtering.

4. The echo cancelation method according to claim 1 or 3, wherein the step B further comprises:

performing, by an AEC module, QMF analysis filtering on a reference audio signal to generate a high-band reference audio signal and a low-band reference audio signal;
performing, by the AEC module, adaptive filtering processing on the low-band reference audio signal to generate a low-band synthesis echo signal; and
performing, by the AEC module, QMF synthesis filtering processing on the high-band reference audio signal and the low-band synthesis echo signal to generate a synthesis echo signal.

5. The echo cancelation method according to claim 1, wherein before the step C, the method further comprises:

generating the preliminary echo cancelation frequency domain signal after the preliminary echo cancelation signal undergoes FFT transformation.

6. The echo cancelation method according to claim 1, wherein the calculating a residual echo suppression coefficient comprises:

calculating energy of each sub-band of the preliminary echo cancelation frequency domain signal, calculating energy of each sub-band of a reference frequency domain signal, calculating energy of each sub-band of a residual echo frequency domain signal, calculating a high-band envelop prediction coefficient, and calculating an attenuation factor of the high-band envelop prediction coefficient;
calculating a gain of each sub-band of a high-band signal in the preliminary echo cancelation frequency domain signal according to the energy of each sub-band of the preliminary echo cancelation frequency domain signal, the energy of each sub-band of the reference frequency domain signal, the energy of each sub-band of the residual echo frequency domain signal, the high-band signal envelop prediction coefficient in the preliminary echo cancelation frequency domain signal, and the attenuation factor of the high-band envelop prediction coefficient; and
calculating a gain of each spectral line of the high-band signal in the preliminary echo cancelation signal, namely, the residual echo suppression coefficient, according to the gain of each sub-band of the high-band signal in the preliminary echo cancelation signal.

7. The echo cancelation method according to claim 6, wherein the method for calculating a high-band signal envelop prediction coefficient in the preliminary echo cancelation frequency domain signal is:

calculating the envelop prediction coefficient according to a formula

$$g_l(i) = \sum_{n=l*N}^{l*N+N-1} h_n(i) * h_n(i) ,$$

wherein
$g_l(i)$ represents the envelope prediction coefficient, N represents a frame length, and $h_n(i)$ represents an echo impulse response of each sub-band of the high-band signal in the preliminary echo cancelation frequency domain signal; and
a method for obtaining $h_n(i)$ is: performing IFFT transformation on a low-band echo filtering coefficient *H(k)* to obtain a low-band impulse response of a time domain, and then performing high-pass filtering processing on the low-band impulse response to obtain a high-band impulse *response* $h_n(i)$.

8. The echo cancelation method according to claim 6, wherein the method for calculating energy of each sub-band is:

calculating energy of a sub-band of an early-stage echo, and calculating energy of a sub-band of a later-stage echo; and
adding the energy of the sub-band of the early-stage echo and the energy of the sub-band of the later-stage echo to obtain the energy of the sub-band.

9. The echo cancelation method according to claim 1, wherein a relationship between the high-band signal in the preliminary echo cancelation frequency domain signal and the low-band signal in the preliminary echo cancelation frequency domain signal is that the two overlaps to eliminate an aliasing effect.

10. The echo cancelation method according to any one of claims 1, 2, and 3, wherein before the dividing a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal, an audio collection device is used to collect the to-be-processed audio signal, wherein the to-be-processed audio signal comprises: an echo audio signal, a local end signal, and a noise signal.

11. An AEC module for echo cancelation, wherein the AEC module comprises:

a reference signal analysis filter, configured to process a reference signal into a high-band reference signal and a low-band reference signal, output the high-band reference signal to an artificial echo synthesis filter, and output the low-band reference signal to an adaptive filter;
a to-be-processed audio signal analysis filter, configured to process a to-be-processed audio signal into a to-be-processed high-band audio signal and a to-be-processed low-band audio signal, output the to-be-processed high-band audio signal to a preliminary echo cancelation signal synthesis filter, and output the to-be-processed low-band audio signal to the adaptive filter;
the adaptive filter, connected to the reference signal analysis filter and the to-be-processed audio signal analysis filter, and configured to perform adaptive filtering processing on the low-band reference signal to generate a low-band artificial echo signal, and output the low-band artificial echo signal to the artificial echo synthesis filter; and perform adaptive filtering processing on the to-be-processed low-band audio signal to generate a low-band preliminary echo cancelation signal, and output the low-band preliminary echo cancelation signal to the preliminary echo cancelation signal synthesis filter;
the artificial echo synthesis filter, connected to the adaptive filter and configured to synthesize the high-band reference signal and the low-band artificial echo signal into an artificial echo signal, and output the artificial echo signal to an RES device; and
the preliminary echo cancelation signal synthesis filter, connected to the adaptive filter and configured to synthesize the to-be-processed high-band audio signal and the low-band preliminary echo cancelation signal into a preliminary echo cancelation signal, and output the preliminary echo cancelation signal to an RES module.

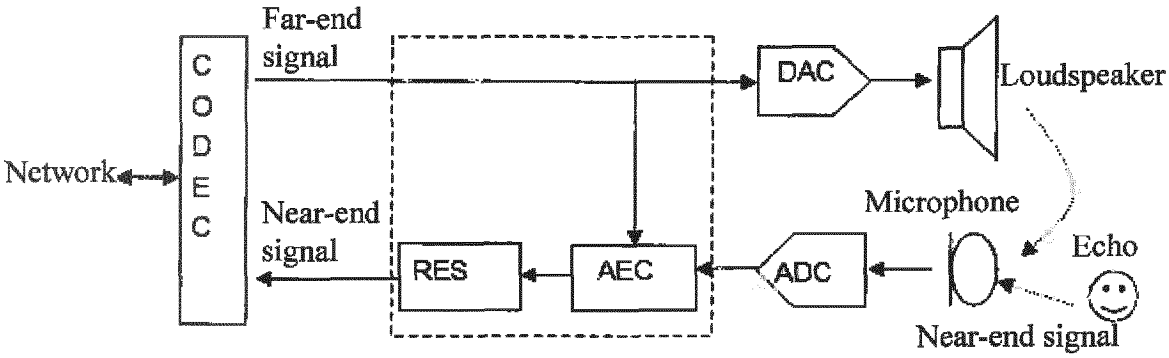
12. An RES module for echo cancelation, wherein the RES module comprises:

an FFT transformation module, configured to perform FFT transformation on a reference signal, a to-be-processed audio signal, an artificial echo signal, and a preliminary echo cancelation signal, to generate a reference frequency domain signal, a to-be-processed frequency domain audio signal, an artificial echo frequency domain signal, and a preliminary echo cancelation frequency domain signal, respectively; and input the to-be-processed frequency domain audio signal, the artificial echo frequency domain signal, and the preliminary echo cancelation frequency domain signal to an RES low-band module, and input the reference frequency domain signal and the preliminary echo cancelation frequency domain signal to an RES high-band module;
the RES high-band module, configured to perform envelope prediction echo suppression on a high-band signal in the preliminary echo cancelation frequency domain signal, and calculate and output a residual echo suppression coefficient; and
the RES low-band module, configured to perform echo suppression on a low-band signal in the preliminary echo cancelation frequency domain signal, and output a processing result.

13. The RES module according to claim 12, wherein the RES high-band module comprises:

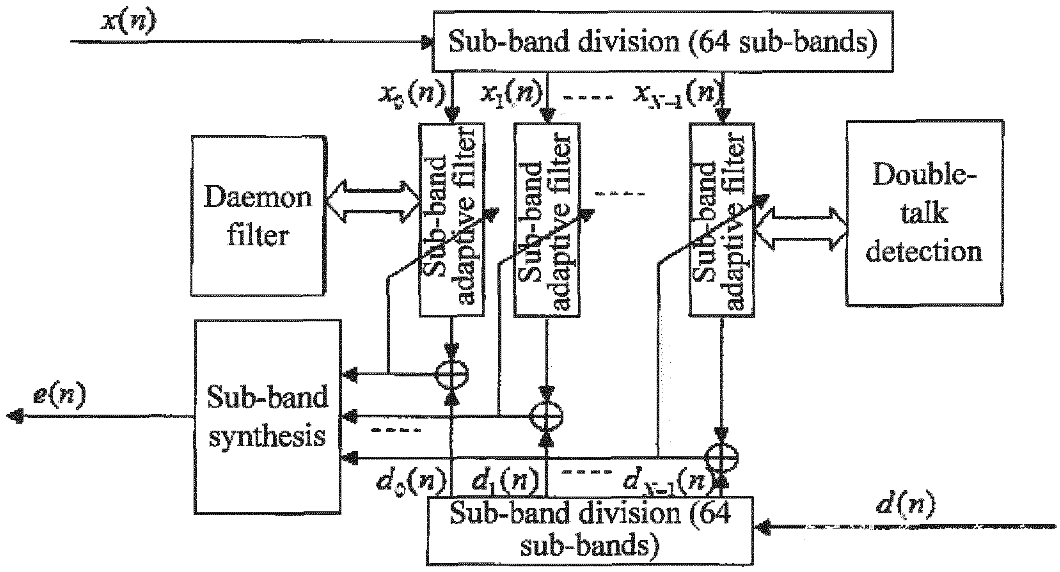
a module for calculating energy of each sub-band of a preliminary echo cancelation frequency domain signal, configured to calculate energy of each sub-band of the preliminary echo cancelation frequency domain signal and output the energy of each sub-band of the preliminary echo cancelation frequency domain signal to a sub-band gain calculation module;
a module for calculating energy of each sub-band of a reference frequency domain signal, configured to calculate energy of each sub-band of the reference frequency domain signal and output the energy of each sub-band of the reference frequency domain signal to the sub-band gain calculation module;
an IFFT transformation module, configured to perform IFFT transformation on a low-band echo filtering coefficient to generate a low-band impulse response of a time domain, and output the impulse response to a high-pass filtering module;
the high-pass filtering module, connected to the IFFT transformation module and configured to perform high-pass filtering processing on the low-band impulse response of the time domain to generate a high-band impulse response, and output the high-band impulse response to a high-band envelope prediction coefficient calculation module;
the high-band envelope prediction coefficient calculation module, connected to the high-pass filtering module and configured to calculate a high-band envelope prediction coefficient according to the high-band impulse response, and output the high-band envelope prediction coefficient to an EDC slope calculation module and the sub-band gain calculation module;
the EDC slope calculation module, connected to the high-band envelope prediction coefficient calculation module and configured to calculate an EDC slope and output the EDC slope to an attenuation factor calculation module;
the attenuation factor calculation module, connected to the EDC slope calculation module, and configured to

calculate an attenuation factor according to the EDC slope, and output the attenuation factor to the sub-band gain calculation module;
the sub-band gain calculation module, connected to the module for calculating energy of each sub-band of a preliminary echo cancelation frequency domain signal, the module for calculating energy of each sub-band of a reference frequency domain signal, the high-band envelope prediction coefficient calculation module, and the attenuation factor calculation module, and configured to calculate a gain of a sub-band according to the energy of each sub-band of the preliminary echo cancelation frequency domain signal, the energy of each sub-band of the reference frequency domain signal, the high-band envelope prediction coefficient, and the attenuation factor, and output the gain of the sub-band to a module for calculating a gain of each spectral line of a high band; and
the module for calculating a gain of each spectral line of a high band, connected to the sub-band gain calculation module and configured to calculate a gain of each spectral line of a high band, namely, a residual echo suppression coefficient, according to the gain of the sub-band.



Far-end signal
CODEC
Network
Near-end signal
RES
AEC
DAC
Loudspeaker
Microphone
ADC
Echo
Near-end signal

FIG. 1



x(n)
Sub-band division (64 sub-bands)
x0(n)
x1(n)
xN-1(n)
Daemon filter
Sub-band adaptive filter
Sub-band adaptive filter
Sub-band adaptive filter
Double-talk detection
e(n)
Sub-band synthesis
d0(n)
d1(n)
dN-1(n)
Sub-band division (64 sub-bands)
d(n)

FIG. 2

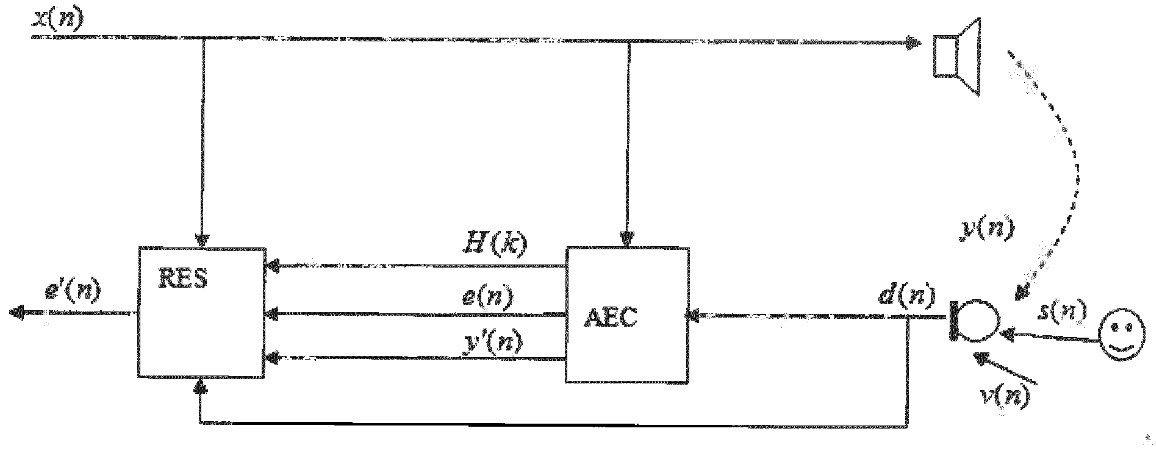

x(n)
H(k)
e(n)
y'(n)
RES
AEC
e'(n)
d(n)
y(n)
s(n)
v(n)

FIG. 3

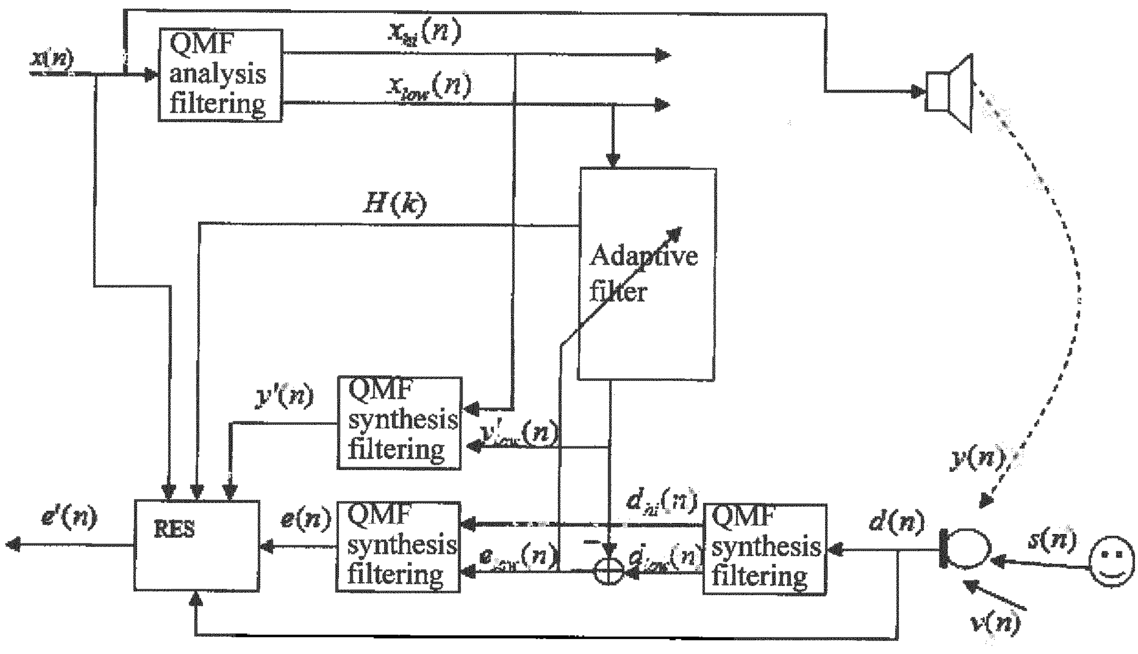

x(n)
QMF analysis filtering
x_hi(n)
x_low(n)
H(k)
Adaptive filter
y'(n)
QMF synthesis filtering
y'_low(n)
e'(n)
RES
e(n)
QMF synthesis filtering
e_low(n)
d_hi(n)
d_low(n)
QMF synthesis filtering
d(n)
y(n)
s(n)
v(n)

FIG. 4

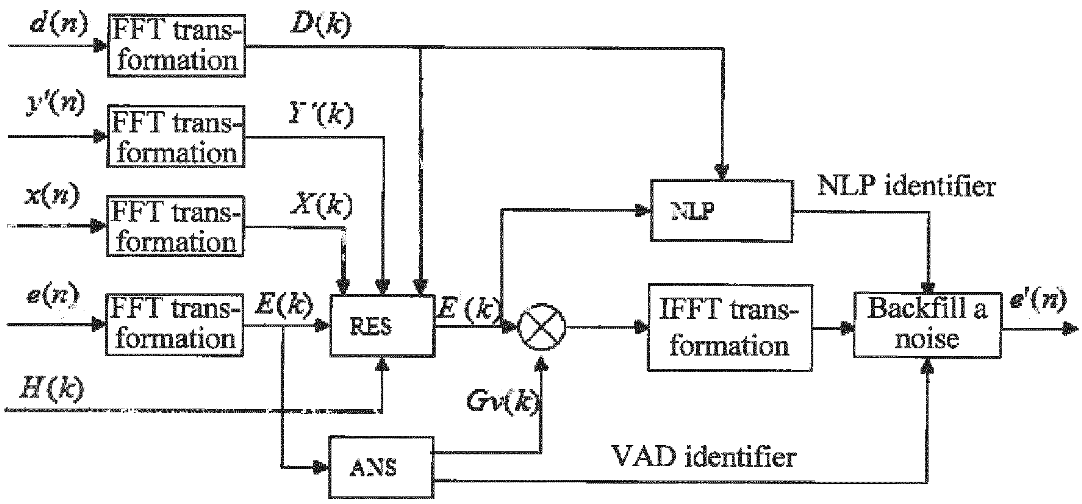

d(n)
FFT trans-formation
D(k)
y'(n)
FFT trans-formation
Y'(k)
x(n)
FFT trans-formation
X(k)
e(n)
FFT trans-formation
E(k)
RES
E'(k)
H(k)
NLP
NLP identifier
IFFT trans-formation
Backfill a noise
e'(n)
Gv(k)
ANS
VAD identifier

FIG. 5

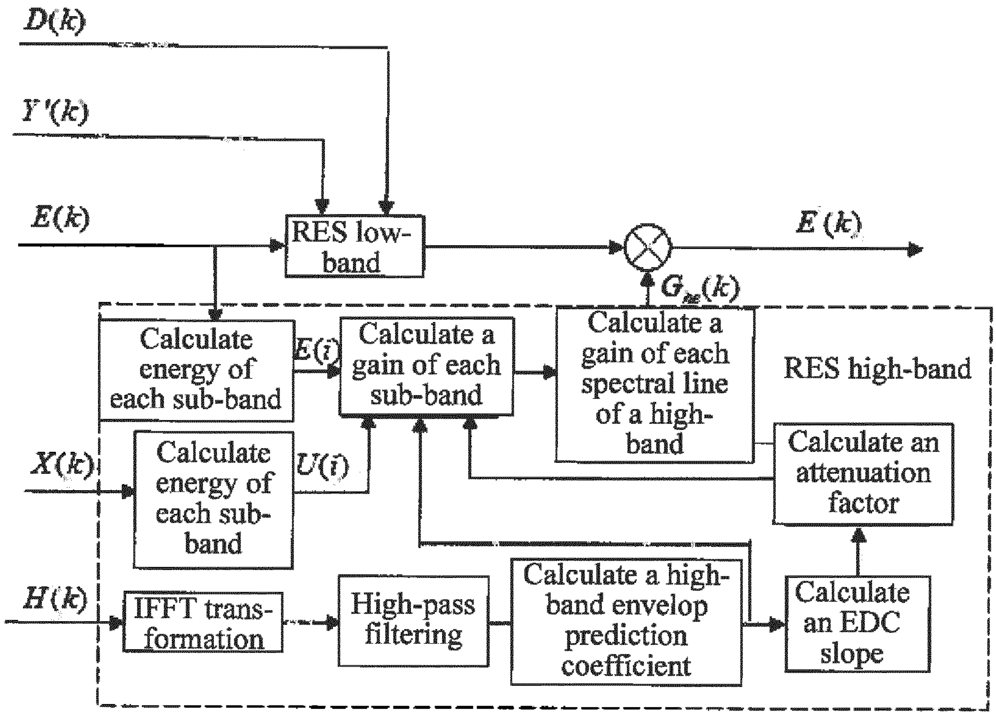
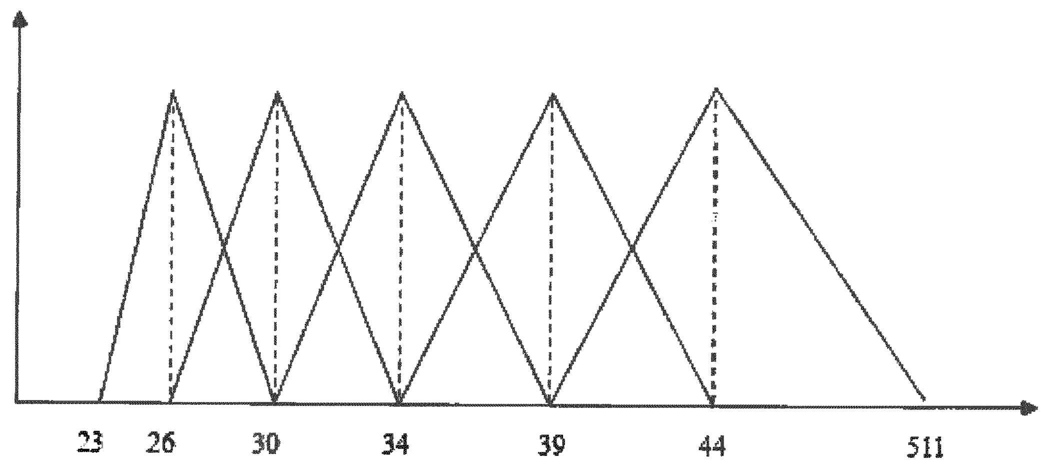

D(k)
Y'(k)
E(k)
RES low-band
E'(k)
$G_{he}(k)$
Calculate energy of each sub-band
E(i)
Calculate a gain of each sub-band
Calculate a gain of each spectral line of a high-band
RES high-band
X(k)
Calculate energy of each sub-band
U(i)
Calculate an attenuation factor
H(k)
IFFT trans-formation
High-pass filtering
Calculate a high-band envelop prediction coefficient
Calculate an EDC slope

FIG. 6


23
26
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34
39
44
511

FIG. 7

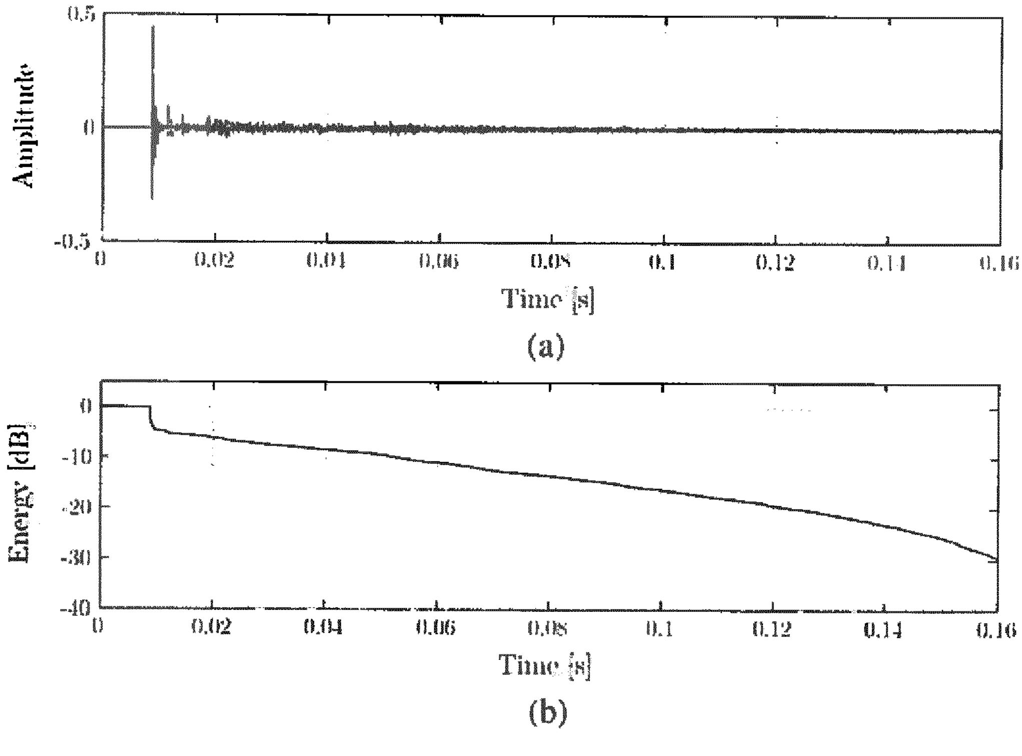
0.5
0
-0.5
Amplitude
0
0.02
0.16
Time [s]
(a)
0
-10
-20
-30
-40
Energy [dB]
0
0.02
0.04
0.06
0.1
0.12
0.14
0.16
Time [s]
(b)

FIG. 8

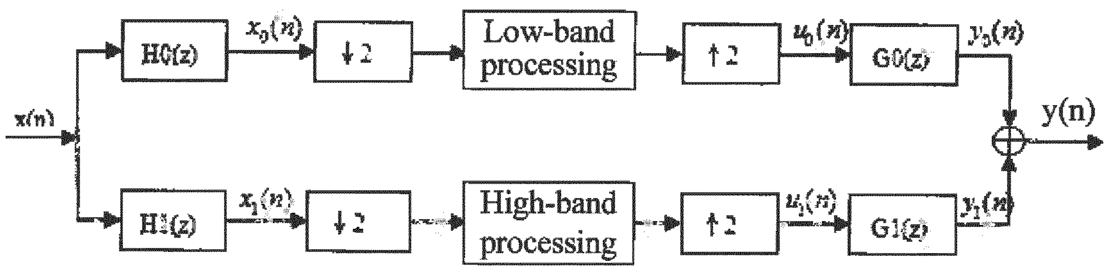
x(n)
H0(z)
$x_0(n)$
↓2
Low-band processing
↑2
$u_0(n)$
G0(z)
$y_0(n)$
y(n)
H1(z)
$x_1(n)$
↓2
High-band processing
↑2
$u_1(n)$
G1(z)
$y_1(n)$

FIG. 9

INTERNATIONAL SEARCH REPORT

International application No.
PCT/CN2013/076685

A. CLASSIFICATION OF SUBJECT MATTER

G10L 21/02 (2013.01) i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: G10L 21/-

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

CNPAT, WPI, EPODOC, CNABS, TWABS, CNKI, GOOGLE: voice frequency, offset, frequency domain, time domain, voice, audio, echo, suppress+, residual, high, low, frequency, time, domain, band, adaptive, filter, envelope

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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A	CN 1805011 A (BEIJING VIMICRO CO., LTD.), 19 July 2006 (19.07.2006), the whole document	1-13
A	CN 101778183 A (HUAWEI DEVICE CO., LTD.), 14 July 2010 (14.07.2010), the whole document	1-13
A	WO 2009/151062 A1 (YAMAHA CORP. et al.), 17 December 2009 (17.12.2009), the whole document	1-13
A	JP 2003284184 A (SONY CORP.), 03 October 2003 (03.10.2003), the whole document	1-13

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:

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"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
20 August 2013 (20.08.2013)	**05 September 2013 (05.09.2013)**

Name and mailing address of the ISA/CN:
State Intellectual Property Office of the P. R. China
No. 6, Xitucheng Road, Jimenqiao
Haidian District, Beijing 100088, China
Facsimile No.: (86-10) 62019451

Authorized officer
YANG, Bin
Telephone No.: (86-10) **82245017**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2013/076685

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Form PCT/ISA/210 (patent family annex) (July 2009)

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/CN2013/076685

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Form PCT/ISA/210 (patent family annex) (July 2009)

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